

An articulatory study of the features ATR in Akan and emphasis in Arabic

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Abstract

Akan contrasts two sets of vowels, one in which the tongue root is advanced and the larynx lowered ([+ATR]), and another in which the tongue root is retracted ([-ATR]) (Lindau, 1979). Arabic contrasts two sets of consonants, one in which the pharynx is constricted ([+emphasis]) and another in which it is not ([-emphasis]). Lindau suggests that the two phenomena can be combined as various settings along a single phonetic dimension of pharynx width, with [+ATR] as maximally expanded and [+emphasis] as maximally constricted, and that this dimension can be reduced to the binary phonological feature [\pm expanded], since no language contrasts more than two settings. This paper tests this hypothesis. Measurements of pharyngeal diameter were taken from X-ray tracings from productions by two Arabic speakers and three Akan speakers, and a multivariate analysis of variance was performed. Although emphasis is primarily a consonant feature in Arabic, it is legitimate to compare vowels in this cross-linguistic study, because as noted by Card (1983), [+emphasis] spreads to vowels and consonants within the same word. The results showed significant interaction between the more and less expanded feature values and the two languages, implying that emphasis in Arabic is controlled by a different mechanism from that used for [\pm ATR] in Akan.

Introduction

This paper compares two features in which pharyngeal width has been implicated -- [\pm ATR] in Akan and [\pm emphasis] in Arabic. Akan has a type of vowel harmony where two sets of vowels contrast; one in which the tongue root is advanced and the larynx is lowered, and as a result the pharynx is wide ([+ATR]), and another in which the tongue root is retracted and as a result the pharynx is narrow ([-ATR]) (Lindau, 1979). The vowels of Akan are as follows:

set 1		set 2	
i	u	ɪ	ʊ
e	o	ɛ	ɔ

a

The low vowel /a/ is neutral with respect to the vowel harmony. The tongue root mechanism involved with [ATR] is usually combined with vertical displacement of the larynx and sometimes with movements of the back pharyngeal wall and is also independent of the mechanism for controlling tongue height (Lindau, 1978).

Some consonant pairs in Arabic (/t/ - /t/, /d/ - /d/, /s/ - /s/, and /z/ - /z/) contrast with respect to the feature "emphasis"; [+emphasis] segments are produced by constricting the pharynx by mainly retracting the tongue. [-emphasis] involves no such constriction or retraction. For example, according to Lindau (1979), Ali & Daniloff (1970) note that 'the articulatory mechanism in the emphatic sounds is such that the tongue moves in a way which depresses the palatine dorsum and moves (mesially) the pharyngeal dorsum (tongue root) towards the pharyngeal wall simultaneously'.

Both of these features have thus been described in terms of using the tongue root to either expand or constrict the pharyngeal cavity. They also do not contrast phonologically in any language. These two observations led researchers to claim that only one feature is needed, [ATR] or [Constricted pharynx], etc., to describe them. For example, Lindau suggests that the two phenomena can be combined and regarded as various settings along the single phonetic dimension of pharynx width, with [+ATR] as maximally expanded and [+emphasis] as maximally constricted. This dimension can then be reduced to a binary phonological feature, [+expanded], under the assumption that one condition for combining two features from two different languages into a single cross-linguistic feature is that both features make use of the same phonetic mechanism. (Lindau prefers [expanded] to [ATR] because she found that the feature involves not only tongue root movement but also larynx movement as well. That is, for [+ATR] segments, the tongue root is advanced but the larynx is lowered, resulting in a larger pharyngeal cavity than that for [-ATR] segments.)

However, what Lindau means by the term 'phonetic mechanism' is not clear. Does it mean an articulator such as the tongue body or tongue root, or a muscle or a group of muscles such as the posterior genioglossus and hyoglossus which cause the tongue root to move forward and backward, resulting in variation in pharyngeal width? The following might clarify her idea about the relationship between articulatory mechanisms and features:

"In both Swedish and Urhobo, the vowels and approximants differ by the use of two separate lip gestures, not by different degrees of the same gestures; So they should be characterized by separate features." (Lindau, 1978:550)

Lindau's statement about [tense] in English and [ATR] in Akan will also help us understand more accurately what she means by 'phonetic mechanism'. She examined the articulatory and acoustic aspects of the feature [tense] in English and concluded that [ATR] and [tense] cannot be combined into a single feature even though [tense] like [ATR] still seems to involve tongue root movement, because in the case of [tense] this movement might be just an artifact of tongue height adjustment for that feature (Perkell, 1971). Her notion of "articulatory mechanism" thus could be interpreted as follows: the same articulators, tongue root and tongue body, are involved in both features, [+ATR] and [tense], but they are controlled by different "phonetic mechanisms", i.e., by a different muscle or a set of muscles. [tense] in English is controlled by the set of muscles that act to raise the tongue body; here the tongue root is advanced as an artifact of this raising movement of the tongue body. By contrast, [ATR] is controlled by a different set of muscles that push the tongue root forward or pull it backward; here the raising and lowering movements of the tongue body are an artifact of the tongue root movement.

Using this same reasoning, we could say that [emphasis] and [ATR] are cross-linguistically different features if they are implemented with qualitatively different tongue root movements and not merely different degrees of the same movement or

gesture. This paper tests Lindau's hypothesis, i.e., that [ATR] and [emphasis] are controlled by the same phonetic mechanism and therefore could be collapsed into the same feature.

To test this hypothesis, the pharynx shape of the vowels in these two languages (pharyngealized/nonpharyngealized vowels in case of Arabic, [+ATR], [-ATR] in the case of Akan) were quantified by measuring several distances between the pharyngeal wall and the tongue root in the pharyngeal cavity. Only /t/ - /t/, /d/ - /d/, /s/ - /s/, and /z/ - /z/ have formerly been recognized as consonants which contrast with respect to [emphasis]. However, [+emphasis] spreads so that all segments in the same word, including vowels, are pharyngealized (Card, 1983). Thus, it is possible to contrast vowels directly so that any difference can be attributed to a real difference of features between the two languages and not to artifacts of primary consonant constriction in Arabic. Arabic has a five vowel system like Akan but with a vowel length contrast. However, the low vowel /a/ in Arabic is affected by [emphatic] spreading to become pharyngealized, whereas the /a/ in Akan is neutral with respect to the [ATR] harmony.

Emphatic segments in Arabic are characterized acoustically by a lower second formant (Card, 1983) whereas a lower first formant characterizes [+ATR] segments in Akan (Lindau, 1979). In order to see if emphasized vowels also show lower F2 frequency compared to unemphasized vowels, I made acoustic measurements on a set of Damascan Arabic productions. As can be seen in Fig. 1, [emphasis] on vowels is also characterized by F2 frequency lowering.

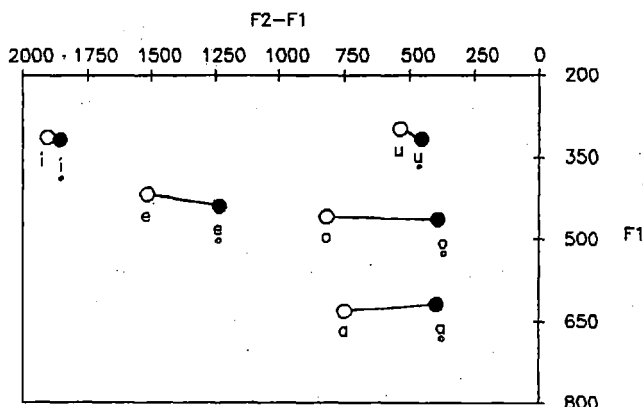


Figure 1. Formant values of emphasized and neutral vowels in Arabic.

Measurements were made from x-ray tracings of three Akan speakers and two Arabic speakers, and statistical analyses were performed on the measurement data.

Two basic claims about the descriptions of these features need to be examined first, however. Are the descriptions of these features in terms of using the tongue root to expand or constrict the pharyngeal cavity accurate? If they are, then the next question is: are the vowels of [+ATR] in Akan and [-emphasis] in Arabic the same in terms of degree of tongue root advancement and also are [-ATR] and [+emphasis] the same? If they are not the same, there would be four different phonetic events regardless of whether all of them can be described in terms of a

single phonetic dimension. Finally, this paper tests whether the features are on the same phonetic dimension, or if they are controlled by different phonetic mechanisms.

Methods

The recordings

The study used an X-ray film in sagittal view of the vocal tracts of two Damascan Arabic speakers and existing tracings of the vocal tracts of three Akan speakers from X-ray films made by Lindau (For a more detailed description of the Akan data, see Lindau (1979)). The Arabic film was made by A. Abramson et al. at Haskins laboratory. The corpora used in the Akan and Arabic films are given below;

Akan

[+ATR]			[-ATR]		
fi	[fi]	'to leave'	fe	[fi]	'to vomit'
bu	[bu]	'to break'	bo	[bu]	'to be drunk'
hwie	[ʃwe]	'to pour'	pe	[pe]	'to like'
mo	[mo]	'well done'	bo	[bo]	'to strike'

Arabic²

[+emphasis]		[-emphasis]	
ʃiid	'hand'	biid	'white (pl.)'
buuz	'ice cream'	buuz	'snout'
beed	'eggs'		
baas	'bus'	baas	'kiss'
tiin	'mud'	tiin	'figs'
tuul	'height'	tuul	'tulip'
teer	'bird'	tees	'goat'
toob	'cannon'	toob	'garment'
taab	'get well'	taab	'reform'
siin	'China'	siin	'letter'
seef	'summer'	seef	'sword'
suum	'feat!'	suum	'ask the price!'
soob	'toward'	soof	'drive'
saah	'crow'	saah	'travel'

Each verb stem in the Akan corpus was in the frame sentence ka...bio "say ... once more" while the Arabic data were read in citation form. Each word in Akan was repeated three times while no repetition was made in the case of the Arabic words.

There is some difference in the corpora of Akan and Arabic in terms of the consonantal contexts of vowels. Every target vowel in Akan is preceded by a labial consonant. However, in Arabic, X-ray tracings for minimal pairs for some vowels preceded by labial consonant were not available. Data for unpharyngealized [e] and for both pharyngealized [o] and unpharyngealized [o] in a labial consonantal context were not available. For these gaps I substituted measurements of each vowel preceded by the alveolar consonants /t/ and /s/, since data for minimal pairs for

every vowel in an alveolar consonantal context were available. A statistical study was conducted to test whether the different preceding consonant could have affected the movement of the tongue for the following vowel, but no significant contextual effects of the consonant on the following vowel were found. The details of this particular test are presented later in this paper.

As mentioned above, the low vowel /a/ in Akan does not participate in vowel harmony while the low vowel /a/ in Arabic is affected by emphatic consonants in the same word. In addition, every vowel in Arabic (with the possible exception of /i/) contrasts with respect to the feature [emphatic]. For most statistical analyses done in the later sections in this paper, measures for /a/ in both languages were excluded from the data. One more difference in the two corpora is that the Arabic data contains only long vowels.

Measurement.

Tracings of the entire vocal tract were prepared from the X-ray video-tape of the two Arabic speakers in the following manner. The whole vocal tract shape on the TV monitor for each vowel was traced on the tracing paper while the tape was on pause. Slowing the tape down to frame-by-frame speed and alternately moving forward and backward on the tape, one frame was chosen as the most steady state for each vowel. Very often around the middle of a vowel there were several identical steady-state frames which occurred at least before the velum had started to move down to the resting position. In those cases, I selected the middle frame as the representative frame for the vowel. For the Akan data, this procedure was not necessary since Lindau had already made tracings using a similar procedure, and photocopies of these tracings were available.

To make measurements, I prepared a template for each speaker as given in Fig. 2, using the following procedure: First, I chose as fixed points some passive articulators - the back wall of the pharynx, the hard palate, Akanthion, and the upper teeth. I drew a vertical line through the back wall of the pharynx (AB) and two horizontal lines perpendicular to it on each tracing for each repetition of each word in both languages. One is from the Akanthion (AC) and another from the highest point of the hard palate (DE). The distance between those two lines for every tracing (AD) was measured and all distances from each speaker were averaged within that speaker. The average value from each speaker was used as a unit for the construction of the template for that speaker. I selected one tracing for each speaker for the representative vocal tract -- the tracing of the first token of the high front [-ATR] vowel /i/ from each Akan speaker and that of high front [-emphasis] vowel /i/ from each Arabic speaker. These were chosen because the average value of the distance between Akanthion and the highest point of the hard palate was closest to that for those vowels. While some tracings deviated from these representative tracings, the deviation was very small in most cases.

The pharyngeal cavity was divided into four sections by drawing four lines perpendicular to the back wall of the pharynx: $DF = FH = HJ = JL = LM$. Since the Arabic tape does not show the lower part of the pharyngeal cavity around the larynx, lines could not be drawn there. The two lowest sections were divided into two subsections by adding one more line for each section: $HN = NJ = JP = PL$. These lines were also perpendicular to the pharyngeal wall. Putting on the template for each speaker on the tracing paper for each token, five distances, HI, NO, JK, PQ, LM, were measured with a ruler whose smallest unit was a millimeter. As mentioned above, some tracings deviated from the template, but the deviation was very small. However, there were two cases in Arabic where HI and NO were not

available (all of them were pharyngealized [a]) because the tongue root was too far down in the pharynx. As a result, I could not use for the statistical analysis the measurement data on those two distances which might give us the information about the shape around the upper pharynx. As an alternative, I chose two more distances (DT and RU): DT bisects $\angle EDF$, and RU bisects $\angle SRB$. RS runs perpendicular from the upper teeth to the pharyngeal wall. In sum, five distances around the pharynx were measured in total: DT, RU, JK, PQ, and LM (I will call them Distance 1, Distance 2, Distance 3, Distance 4, and Distance 5, respectively).

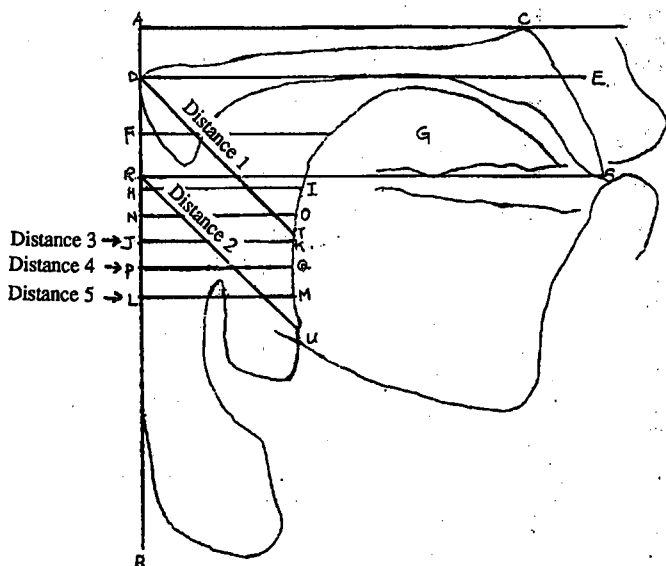


Figure 2. Construction of 5 distances: DT, Distance 1; RU, Distance 2; JK, Distance 3; PQ, Distance 4; LM, Distance 5.

Results

Consonantal contextual effect on vowels

As mentioned above, in Arabic, at least three different consonants precede the target vowel in the corpus, -- the bilabial stop /b/, the dental stop /t/, and the dental fricative /s/ -- while in Akan, labial consonants always precede the target vowel. Several researchers (e.g., Stevens & House, 1955), have reported a consonantal contextual effect on vowels. If this contextual effect is present in Arabic, a straightforward comparison of some Akan and Arabic vowels would not be possible. If there is an effect, I need to deduce the effect of the labial consonant on the vowel /e/ or /i/ for which the labial context is missing by comparing the effect of labial consonant and dental consonant on the other vowels and limit the corpus to the words or phrases which start with the labial consonant.

In order to test whether different consonantal contexts affect the following vowels significantly with respect to [emphasis], I performed an Analysis of

Variance and also a Multivariate Analysis of Variance on the measures for the three vowels other than /e/ and /o/. The five distances were the dependent variables and the three different consonants were the independent variables. If the contextual effects of consonants on the following vowels are significant, there should be significant main effect of consonantal context. ANOVA and also MANOVA showed no significant main consonantal effect on any distances ($\alpha = 0.01$). Based on this result, I conclude that different consonantal context would not affect the results of the statistical analyses I will perform later in this study.

The vowel /i/

Based on formant measurements, Card (1983) reports that /ii/ and some consonants in Palestinian Arabic are not affected by the emphatic consonants and block the spreading of emphasis; the second formant of /ii/ is not lowered and the second formants of the preceding or the following segments in the same word are not lowered even in the emphatic environment. To see whether /ii/ in Damascan Arabic is affected by the emphatic consonant, I only took data for Arabic /ii/s and performed an ANOVA and MANOVA. There were no significant differences between /ii/ in the non-emphatic condition and /ii/ in the emphatic condition, demonstrating that /ii/ in Arabic is not affected by emphatic consonants. (i.e. it does block the spread of emphasis) The image tracings of two vowels given in Appendix show almost no difference in vocal tract shape, especially in the pharyngeal cavity. Therefore, measures for the high front vowel /i/ and /ii/ in both languages were excluded from the data for the statistical analyses done in the later sections.

Characterizing the features in qualitative terms

As mentioned above, measures for the low vowel /a/ and the high front vowel /i/ in both languages were excluded from the data for the statistical analyses done in this and later sections in this paper because of neutrality of /a/ with respect to vowel harmony in Akan and neutrality of /i/ with respect to [emphasis] in Arabic. To verify whether previous descriptions of [ATR] as an expansion of the pharyngeal cavity and [emphasis] as a constriction of the pharyngeal cavity are accurate, separate ANOVA and MANOVA were performed for each language on the same measurements as before with the five distances as the dependent variables and the two values of the feature for the language as the independent variables. If the descriptions of these features are accurate, there should be a significant main effect of feature and the mean should be smaller for the more constricted value.

As can be seen in Fig. 3, the main effect of feature for all distances was significant in Akan. In Arabic, the main effects of feature for all distances except for the 2nd distance were significant and the main effect in the MANOVA was also significant ($P < 0.0001$).

Note, however, that the means for distance 1 in Arabic do not differ in the direction we would expect. Given the description that pharyngealized vowels show a greater constriction in the pharynx, they should have smaller means for all relevant distances. Instead, the mean for this distance for [+emphasis] was larger than that for [-emphasis]. This may be because the tongue root moves backwards and simultaneously lowers farther down for [+emphasis] in Arabic. Even though the measurement data for /a/ in both languages are not included in this study because of the neutrality of /a/ with respect to the ATR harmony in Akan, there were two cases in Arabic where the tongue root lowers so much that I could not get the value of distances HI and NO which are right above the distance 3 in Fig.2. On

the other hand, all five distances in Akan differ in the direction we would expect, i.e. means of distances for [+ATR] are larger than those for [-ATR].

From these results we could conclude that the descriptions of [ATR] and [emphasis] are generally accurate: the tongue root is involved in these features. However, there seems to be some difference with respect to which part of the pharynx is constricted by these features: [+emphasis] in Arabic involves constriction in the lower pharynx whereas [-ATR] in Akan involves constriction of the whole pharynx. This difference seems to imply that these two features are controlled by different phonetic mechanisms, which we test in section 3.5. in this paper.

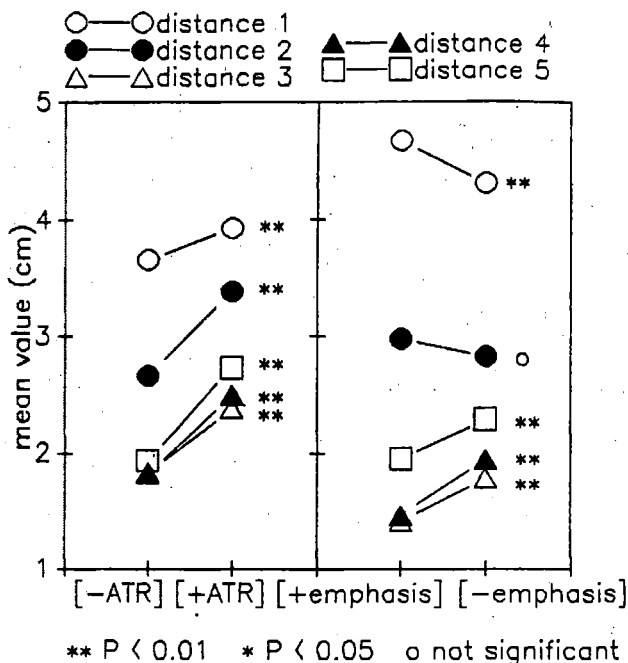


Figure 3. Effects of features, [ATR] in Akan and [emphasis] in Arabic.

Comparing wide and narrow pharynx values across the languages.

The next question to be raised is whether [ATR] and [emphasis] are ultimately the same feature or not: Are [+ATR] and [-emphasis], both characterized by a wide pharynx, the same? Are [-ATR] and [+emphasis], both characterized by a narrow pharynx, the same? If the members of the pairs above are implemented differently, then there could be four levels of pharyngeal width or shape, regardless of whether they are on the same phonetic dimension or not. In order to test this, an ANOVA and MANOVA were performed on the same measurement data above but it is organized differently. The five distances were dependent variables and the two languages within each value of two (wide pharynx and narrow pharynx) were independent variables. If [+ATR] and [-emphasis] or [-ATR] and [+emphasis] are

the same, there should be no main effect for either the wide-pharynx feature or the narrow-pharynx feature.

As shown in Fig. 4, the effect of language within the wide-pharynx vowels was significant for all distances except for the 5th, and the effect of language in the MANOVA was also significant. The effect of language within the narrow-pharynx vowels for all distances were significant. The effects of language in the MANOVA was also significant ($P < 0.0001$).

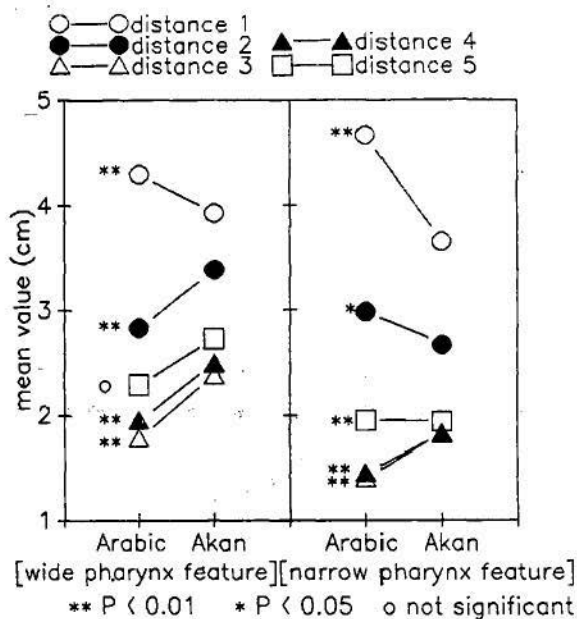


Figure 4. Wide and narrow pharynx values across Akan and Arabic.

Based on these results, we could conclude that [+ATR] and [-emphasis] are different from each other with respect to the five distances around the pharynx constructed for this study. [-ATR] and [+emphasis] are different as well. In other words, there are four levels of pharyngeal width. Once four different levels of pharyngeal width are established, the next question to be raised is whether those four levels are in the same phonetic dimension or not, as proposed by Lindau.

Comparing the contrasts across the languages

In order to test the hypothesis that [ATR] and [emphasis] are controlled by the same phonetic mechanism such that they are phonetically the same or they are in the same phonetic dimension, an ANOVA was performed on the same measurement data with the five distances as the dependent variables and language and feature as independent variable. If [ATR] in Akan and [emphasis] in Arabic contrast phonologically in each language, and these features are controlled by the same phonetic mechanism, we could expect a statistically significant main effect of language but an insignificant interaction between language and feature as given hypothetically in Fig. 5a. On the other hand, if they are controlled by a different

phonetic mechanism, we should expect both a significant main effect of language and a significant interaction between language and feature as exemplified in Fig. 5b and 5c.

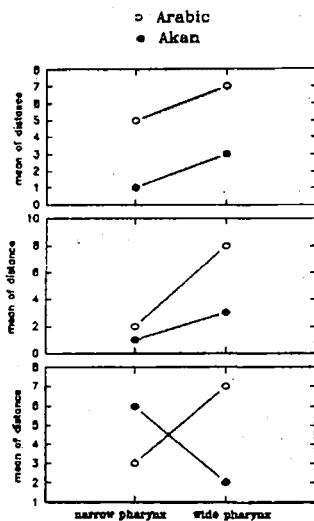


Figure 5. Schematized hypothetical data in interaction between languages and feature: Not significant (a) vs. Significant (b, c).

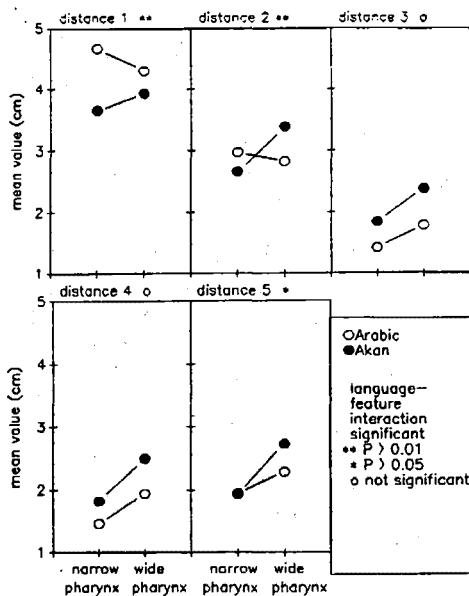


Figure 6. Interaction between language (Akan and Arabic) and feature ([ATR] and [emphasis]).

As in section 3.3, there was a significant main effect of language. As shown in Fig. 6, the 1st, 2nd and 5th distances gave a significant interaction between language and feature. The MANOVA also yielded a significant interaction between language and feature ($P < 0.0001$).

These results seem to demonstrate that Lindau's hypothesis that [ATR] and [emphasis] involve the same phonetic mechanism is not correct. Rather, these features are controlled by some different phonetic mechanisms. The patterns described in section 3.3 suggest that they might involve different parts of the pharynx.

Discussion and Conclusion

In this paper, I have tested Lindau's (1979) hypothesis that [ATR] in Akan and [emphasis] in Arabic are controlled by the same phonetic mechanism by taking measurements from x-ray tracings of some distances between the tongue root and the back wall of the pharynx in sagittal view.

Before I tested this hypothesis, I first tested whether the previous descriptions of these features in terms of using the tongue root to expand or constrict the pharyngeal cavity were correct. Statistical analysis of the articulatory measurement data done in this study confirmed the description. I then examined whether [+ATR] and [-emphasis] are phonetically the same value, and likewise for [-ATR] and [-emphasis]. Statistical analysis of the measurement data shows that they are different from each other, and that there are four levels of pharyngeal width involved.

Finally, Statistical analysis of the measurement data strongly suggests that [ATR] in Akan is controlled by a different phonetic mechanism from [emphasis] in Arabic. [ATR] and [emphasis], therefore, cannot be combined and regarded as various settings along a single phonetic dimension of pharynx width as Lindau proposed.

In order to figure out what mechanisms control [ATR] in Akan and [emphasis] in Arabic, we need further study. Investigating which muscle or muscles are active with these features using EMG, for example, might illuminate the mechanism.

Notes

*The original version of this paper was presented in the 119th meeting of the Acoustical Society of America, State College, Pennsylvania, May 1990.

1. According to Card (1983), the four emphatic obstruents are : /t̤, d̤, s̤, ʃ̤ / In Classic Arabic. /z/ and /z̤/ are used in many urban colloquial dialects in place of /ʃ̤/ and /ð̤/ in Classic Arabic.

2. Dots under the consonants in Arabic data indicate that they are primary emphatic consonants.

References

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Appendix Image scans of /ii/ of /ʔiid/ and /biid/ in Arabic.

/ʔiid/ (neutral condition)

/biid/ (emphatic condition)

